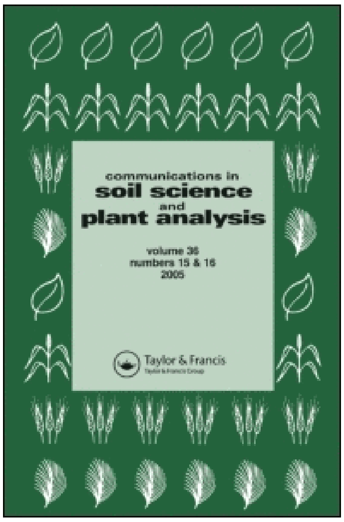

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Effects of Various Preplant and In-Season Nitrogen Management Practices for Potatoes on Plant and Soil Nitrogen Status

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Effects of Various Preplant and In-Season Nitrogen Management Practices for Potatoes on Plant and Soil Nitrogen Status

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Abstract: Adequate availability of nitrogen (N) to satisfy potato crop N requirement is critical for production of optimal tuber yields with high processing qualities, which will contribute to maximum net returns. The agroclimatic conditions in the Columbia Basin region in the Pacific Northwest (PNW) supports high potato tuber yields with high processing qualities. Best management of N fertilization is important to increase N uptake efficiency and to minimize N losses. Monitoring soil and petiole N provides a basis to evaluate available N in the soil and N status in the plants. This study was conducted on a Quincy fine sand (mixed, mesic Xeric Torripsamments; >95% sand) using 'Ranger Russet' potato cultivar. Potato followed by 2 years of sweet corn rotation was adapted in this study. Treatments included the following preplant (PP) + in-season (IS) N rates in kg ha^{-1}: (i) 56 + 280, (ii) 112 + 224, or (iii) 112 + 336 in 2004 or 112 + 112 in 2005. The IS N was applied in five equally divided doses at 2-week intervals, 3 weeks after seedling emergence. An additional treatment was included with treatment (ii) N rates, except that IS N was delivered in 10 weekly applications. Total tuber yield ranged from 54 to 64 and 78 to 90 Mg ha^{-1}, respectively, in 2004 and 2005. In 2004, during the first 65 days after emergence (DAE), petiole nitrate (NO_3) concentration was lower in the treatment (i) than that in the other treatments. This difference was not evident in 2005. The petiole NO_3 concentrations were lower in 2005 than that in 2004, particularly during latter part of the growing period. Soil available N [nitrate NO_3-N + ammonium (NH_4) N in the top 30 cm] concentrations were also greater in 2004 than those in 2005. Soil N appeared to increase toward the end of the growing season in 2004,

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which has negative effects on tuber yield and quality. Across all treatments, total tuber yield and that of >340-g grade tubers were greater in 2005 than that in 2004.

Keywords: Ammonium, best management practice, Nitrate, nitrogen losses, nitrogen requirement, petiole nitrogen, tuber quality

INTRODUCTION

Pacific Northwest (PNW) states in the United States (i.e., Washington, Oregon, and Idaho) represent an important potato production region in the country. This region contributes to 56% of the total potato production (19.2 million metric tons, National Potato Council 2006) in the country. The U.S. potato production ranks fifth in the world (359 million metric tons) behind Russia, China, India, and Ukraine. Total potato production values in Idaho, Washington, and Oregon are 5.4, 4.3, and 1.0 million metric tons, and these states rank 1, 2, and 6, respectively, in the nation.

Potato industry in the PNW has changed considerably over the years. Along with the changes in production practices, the cultivar composition of the industry has also changed. Up until the late 1990s, 'Russet Burbank' was the major cultivar used. In 1997, this cultivar accounted for 80, 50, and 31% of the total potato acreage in Idaho, Washington, and Oregon, respectively (Jensen 2006). By 2005, the respective percentages were down to 63, 40, and 15. During the same period, the percent acreage under 'Ranger Russet' increased from 4 to 15 in Idaho and 2 to 25 in Oregon. That for Washington remained steady at 16% from 1997 to 2005. The substantial increase in adoption of the 'Ranger Russet' cultivar and the need to develop best management recommendations for nitrogen (N) fertilization of potato on sandy soils based on monitoring of soil and plant N status thus contributed to the need for research into optimization of N management on potatoes in the PNW.

Monitoring N status in soil and/or plants provides a basis for evaluating the N pool in the soil as well as an index of plant N status. The information can then be used to evaluate the optimal crop N requirement aimed to improve N uptake efficiency and minimize N losses. For potatoes, petiole NO_3-N analysis has been evaluated as an index of N status in the plants (Gardener and Jones 1975; Roberts and Cheng 1988; Williams and Maier 1990; Westcott, Stewart, and Lund 1991; Westcott, Rosen, and Inskeep 1993; Dean 1993; Westermann 1993; Vitosh and Silva 1994, 1996). In sandy soils, which are predominant in the potato production region in the PNW, soil analyses for nitrate (NO_3)-N is not a reliable index of soil available N pool.

The petiole NO_3-N status also can vary across different cultivars and production conditions. The objective of this study was to evaluate the petiole NO_3-N status in 'Ranger Russet' cultivar and soil N pools in a sandy soil under a range of N management programs in a typical PNW potato production condition with high tuber yields.

MATERIALS AND METHODS

The field experiment was conducted in Benton County, WA, using a Quincy fine sand (mixed, mesic, Xeric Torripsamments). This soil is representative of the major potato-growing region in the Columbia Basin across Washington and Oregon, with sand content ranging from 92 to 95%. This site has been under potato rotation production system since 1992. Initially, the rotation was potato, wheat, then 2 years of field corn. As of 2003, a 3-year rotation system was adapted as potato followed by 2 years of sweet corn. The site was irrigated by a center pivot (Zimmatic three-span; Lindsay Manufacturing, Lindsay, NE) equipped with Nelson N-3000 rotators sprinkler package (Nelson Irrigation, Walla Walla, WA) at 3.05-m spacing with delivery rate of 10 gallons per minute at 50 psi. The planting was done on north–south row over an area of 1.6 ha, which occupied a quarter of the 8.4-ha pivot circle. This facilitated all major cultivation operations to be done using commercial equipments. Preplant N rates (using urea; as per the different treatments) and blanket rates of P and potassium (K), at 35 and 110 kg ha^{-1}, respectively, were broadcast using Valmar Model 500 PT spreader (Valmar Airflo, Manitoba, Canada) followed by tillage using Sunflower JD 8760 (Sunflower Manufacturing, Beloit, KS) and Schmeiser packer (T. G. Schmeiser Company, Fresno, CA). Postplant tillage was Dammer Diking using a six-row Dammer Diker (Ag Engineering, Pasco, WA). This operation was to minimize water runoff along the furrow. After seedling emergence, the irrigation was scheduled to replenish the daily evapotranspiration (ET) losses. A standard program of weed, pest, and disease management was followed each year as recommended by the Washington State University Cooperative Extension for production of high-processing-quality tubers. Nitrogen treatments included (kg ha^{-1} N as preplant and in-season application) (i) 56 + 280, (ii) 112 + 224, and (iii) 112 + 336 in 2004 or 112 + 112 in 2005, with four replications. Total N rates used in this study varied from 224 to 448 kg ha^{-1}, which represents the range of N rates recommended for production of 45 to 78.4 Mg ha^{-1} high-quality potato tubers in this region (Lang et al. 1999; Dean 1993; Dow 1974; Gardner, Jackson, and Fitch 1985; Painter et al. 1977). The in-season N rate was delivered in five applications, spaced 2 weeks apart, 12 May through 14 July 2004 or 23 May through 25 July 2005. An additional treatment with 10 weekly applications of the in-season N was also evaluated at the N rates in treatment (ii).

In-season N was applied as urea ammonium nitrate (UAN, 32% N) delivered using tractor–driven boom sprayer. Although in-season N was applied over the crop canopy, because of the large amount of water applied as irrigation immediately following application of IS N, most of applied N was washed out of the canopy into the soil. Thus, N uptake of the N delivered as in-season application was primarily by the roots. Irrigation was scheduled to replenish the daily ET loss. Cumulative irrigation over the growing season was recorded.

Petiole samples were taken beginning from 35 DAE in 2004 and 30 DAE in 2005. Within a plot, 15 to 20 plants were randomly sampled. Fourth fully expanded leaf was used for petiole sampling. The pooled samples from each plot were oven dried at 72 °C and ground, and a 0.2-g ground petiole sample was extracted in 50 ml 4% acetic acid. The concentrations of NO_3-N were analyzed in a rapid flow analyzer (Flow Injection Analyzer, 8000, Lachet Instruments, Milwaukee, WI).

Soil samples were taken at various intervals during the growing season (35, 60, 90, 125, and 165 days after planting in 2004, and 15, 35, 70, 105, 140, and 170 days after planting in 2005) at depth increments of 0–15, 15–30, 30–60, and 60–90 cm. These samples were stored in sealed plastic bags, placed in an ice chest, transported to the laboratory, and stored in a refrigerator at 4 °C. The field-moist soil sample was extracted in 2M potassium chloride (KCl) at 1:10 ratio of soil–extractant. The suspension was shaken in an end-over-end shaker and centrifuged for 10 min at 3000 rpm, and the supernatant was filtered through Whatman no. 42 filter paper. A rapid-flow analyzer was used to measure the concentrations NO_3-N and ammonium (NH_4) N. Gravimetric soil water content in the soil was used to calculate the concentrations of NO_3-N and NH_4-N on oven-dry soil weight basis. The sum of NO_3-N and NH_4-N in the top 30-cm depth was used for comparison between the treatments.

RESULTS AND DISCUSSION

In 2004, total tuber yield varied from 54.4 to 64.2 Mg ha^{-1} across the four N management treatments (Figure 1). Tuber yield was significantly lower with 56 + 280 kg ha^{-1} N treatment as compared to that in the other treatments. At a given N rate, frequency of in-season N application (5 vs. 10) had no significant affects on total tuber yield and/or distribution of tubers in different size-grade classes. In 2005, however, tuber yield was not significantly influenced by any of the N management treatments.

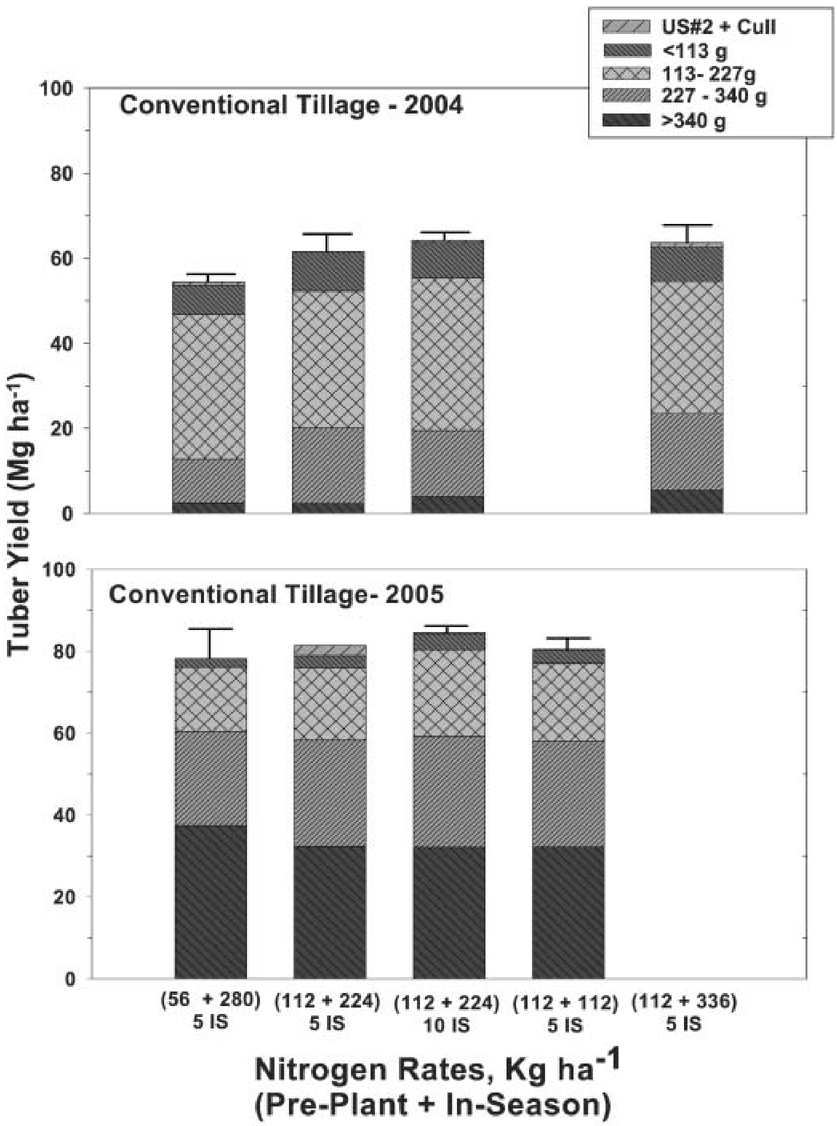

Figure 1. Effects of different pre-plant and in-season (IS) nitrogen applications to 'Ranger Russet' potato cultivar grown in a Quincy fine sand, 2004 and 2005. Total tuber yield and yields of tubers in different size grades are shown. Standard error for the mean total yield for each treatment is shown at the top of each histogram.

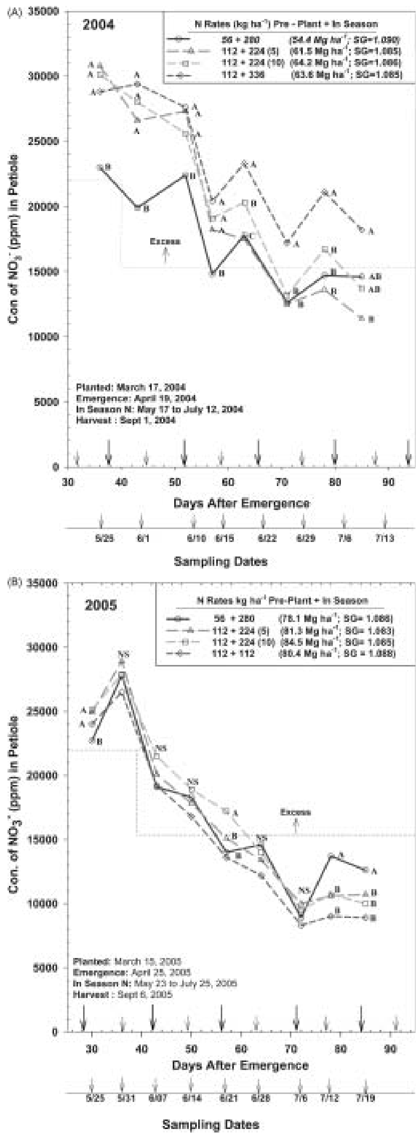

Figure 2. Petiole NO_3^-concentrations for 'Ranger Russet' potato cultivar grown in a Quincy fine sand with different pre-plant and in-season nitrogen applications in 2004(a) and 2005(b). Total tuber yield and tuber specific gravity (SG) for each nitrogen management treatments are shown in the respective figures. The arrows along the x-axis represent the timing (in relation to days after emergence) of in-season nitrogen applications: (i) long arrows for 5 in-season applications; and (ii) long and short arrows for 10 in-season applications. Treatment means followed by similar letters, by each sampling date, are not significantly different (P=0.05) by Duncan's mean separation test. NS= No significant difference between the four N management treatments.

Petiole sampling in 2004 began 35 DAE and continued on a weekly interval until 85 DAE. Initially, the petiole NO_3^- concentrations were up to 30,000 ppm in all N management treatments, except 56 + 280 kg ha^{-1} treatment (Figure 2a). Petiole NO_3^- concentrations decreased through the growing period. About 60 DAE, the petiole NO_3^- concentration was greater in 112 + 336 kg ha^{-1} N treatment as compared to those in the other treatments. Overall, the petiole NO_3^-concentrations were in the excess range up to about 65 DAE but remained close to the recommended optimal level during the later growing period, except for the 112 + 336 kg ha^{-1} N treatment. The petiole NO_3^- concentrations in the latter were greater than the critical optimum level. It should be noted that the petiole critical concentrations are derived from the research done on 'Russet Burbank' cultivar. The calibration of the petiole critical concentrations for other cultivars has not been worked out. However, we assume that these critical concentrations do provide valuable guidelines for evaluation of nutritional status of other potato cultivars as well. Further research is necessary to develop critical petiole nutrient concentrations for other major potato cultivars.

In 2005, the petiole NO_3^- concentrations were generally lower than those in 2004 (Figs. 2a and 2b). The differences in petiole NO_3^- concentrations across different N management treatments were rather marginal until about 75 DAE. During the later period, the petiole NO_3^- concentrations were greater in the 56 + 280 kg ha^{-1} treatment as compared to those for the other treatments.

Available soil N is measured in 2M KCl extraction of the soil within the rooting depth. For potatoes, the majority of roots are within soil in the top 30 cm. Soil samples were taken at depths of 0–15 and 15–30 cm at a monthly interval starting from 40 and 10 days after planting (DAP) in 2004 and 2005, respectively. In 2004, the KCl-extractable NO_3-N plus NH_4-N in the top 30 cm varied from 120 to 200 kg ha^{-1} at the first sampling (40 DAP) (Figure 3a). The extractable N level declined sharply, across all treatments, and remained at about 60 kg ha^{-1} during 90 to 130 DAP. Subsequently the soil N status increased to about 70 kg ha^{-1} in the 56 + 280 and 112 + 224 (10 applications of the in-season N) kg ha^{-1} N application treatments. In the remaining two treatments, the soil N status increased 90 to 110 kg ha^{-1}. Slight increase in soil available N status toward the end of growing season in potato production is due to mineralization of N from plant residues, which are returned to the soil following plant senescence and devining plants in preparation for harvesting the tubers. The mineralized N at this late stage of the growing season has no sink because there is no plant uptake of available soil N.

The soil N status overall was less in 2005 as compared to that in 2004 across all treatments and all samplings (Figures 3a and 3b). In

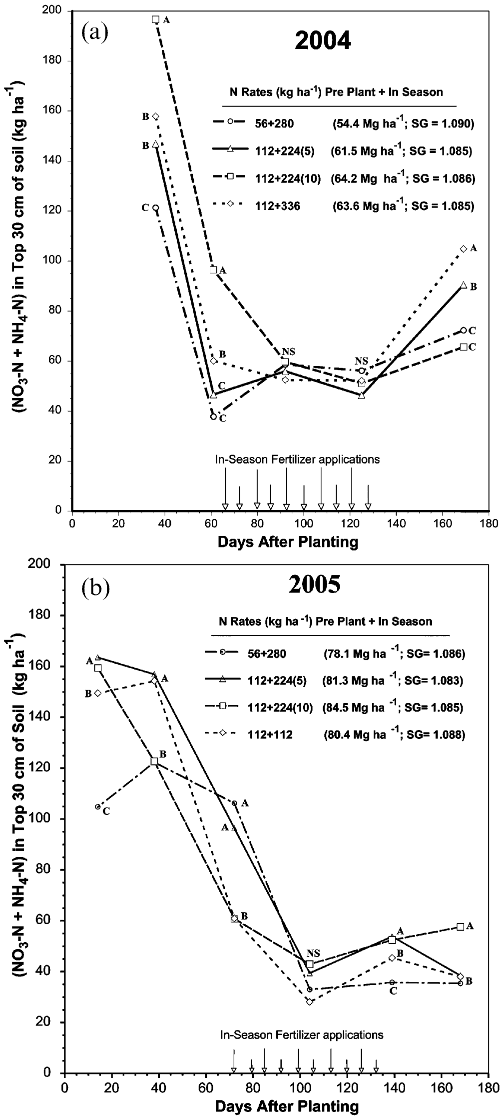

Figure 3. Nitrogen status in a Quincy fine sand sampled during the growing season of 'Ranger Russet' potato cultivar as influenced by different pre-plant and in-season nitrogen applications in 2004(a) and 2005(b). Arrows along the x-axis indicate timing of in-season nitrogen applications. Tuber yield response and tuber specific gravity (SG) for each N management treatments are also shown. Treatment means followed by similar letters, by each sampling date, are not significantly different (P=0.05) by Duncan's mean separation test. NS= No significant difference between the four N management treatments.

2005, initially (10 DAP) the sum of NO_3-N and NH_4-N varied from 105 to 165 kg ha^{-1} but decreased sharply across all treatments and attained concentrations close to 40 kg ha^{-1} by 100 DAP. Unlike the 2004 results, in 2005, the soil N status remained low (40–55 kg ha^{-1}) 100 DAP.

About 100 DAP, major portion of the shoot and tuber nutrient accumulation was completed (Pan and Hiller 1992). Furthermore, the nutrient uptake capacity of potato roots is reduced significantly during bulking stage because of a significant decline in root length. Excess N availability during late season affects the tuber quality and yield by stimulation of regrowth, which in turn decreased the accumulation of photosynthates in the tuber (Lauer 1984). Petiole NO_3^- levels continue to decline toward the later part of the growing season, which is an indication of low N demand toward the end of the growing season. Therefore, an increase in extractable N status in the soil toward the end of the growing season thus suggests potential negative affects on tuber yield and quality.

Petiole N concentrations are generally high early during the growing period and decrease towards the end of the growing period, with the sharp decline during the tuber bulking stage. The optimal ranges of NO_3-N concentration in the petiole are 15,000 to 22,000, 12,000 to 15,000, and 6,000 to 10,000 ppm during tuber initiation, tuber bulking, and tuber maturation stages, respectively (Jones 1975; Painter 1978; Westermann and Kleinkopf 1982).

Petiole NO_3^- concentration can decrease toward the latter part of the growing season, either due to a reduction in available soil N or due to a reduction in ability of plants to take up N from the soil. During the first 80 DAE, much of the N is accumulated in the shoots, which in turn is translocated to the tubers during the subsequent period (Kunkel, Holstad, and McNeal 1977; Kleinkopf and Westermann 1980).

Soil N extractable by KCl is an indicator of N available for plant uptake. Concentrations of soil N (as NO_3-N + NH_4-N) of 10 to 15 ppm in the top 45 cm of soil are generally adequate to maintain petiole NO_3-N in the optimal range. This is equivalent to about 67 to 100 kg ha^{-1} for the top 45 cm of soil. Because the majority of the roots are in the top 30 cm for the soil type used in the current study, representative of the Columbia Basin production region, the soil N in this depth is important to determine the plant response. For the top 30 cm, the optimal soil N corresponds to about 45 to 67 kg ha^{-1}. Accordingly, the soil N in the current study in both years was more than the critical range except for a short period in 2005 (Figures 3a and 3b). The recommended soil N (NO_3-N + NH_4-N) concentrations in the top 45 cm of soil are >10 to 15 ppm, 10 ppm, and <10 ppm during tuber initiation, bulking, and maturation stages, respectively (Westermann and Kleinkopf 1982).

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